CHAPTER 10

# COMPACTION OF SOIL

دمك التربة عملية ميكانيكية الغرض منها تحسين خواص التربة وبالخصوص مقاومتها . وهى عملية تتم أحيانا فى الموقع على التربة الطبيعية لرفع مقاومتة الطبقة الواقعة أسفل اساس منشأ مباشرة أو أسفل أساس طريق ، أو تتم على طبقة مستجلبة من التربة توضع كطبقة إحلال أسفل الأساس حيث يشترط ان تتم على الطبقات صغيرة السمك نسبيا للوصول بكثافتها الجافة الى قيمة عالية مشروطة مسبقا .

وتتم عملية الدمك مع إضافة المياه الى التربة بدرجة مناسبة حيث وجد عمليا أن صغر محتوى الرطوبة بالتربة قد لا يكون كافيا لتسهيل عملية الدمك وإعطاء فاعلية (تليين) لتحريك حبيبات التربة . فى نفس الوقت فإن زيادة محتوى الرطوبة يؤدى الى ابتعاد الحبيبات عن بعضها . ولذلك فان كل نوع من التربة محتوى رطوبة هو "الأمثل" لعملية التلين اثناء الدمك . ويعتمد محتوى الرطوبة الأمثل والكثافة الجافة القصوى للتربة على كمية الطاقة المبذولة فى الدمك ونوع التربة .

Compaction is a process by which the soil particles are artificially re-arranged and packed together in a closer state of contact by mechanical means. Such process causes decrease of the porosity of soil, and thus causes increase of its dry density compaction is different from consolidation, it is mainly a rapid reduction in the air voids under a load of short duration.

## 10.1 Compaction characteristics and soil type

For particular soil placed in the field, the required mechanical properties can be attained depending on the density and water content, together with the type of the placed soil. It was experimentally found that for a particular compaction energy there exists a definite relationship between the soil water content and the dry density which a soil might be compacted. This relationship is characterized by an increase in the dry density with the increase of water content up to certain value $(\gamma_d)_{max.}$ at which the water content is called the optimum moisture content (O. M. C.) after which an increase in the water content results in a reduction of dry density.

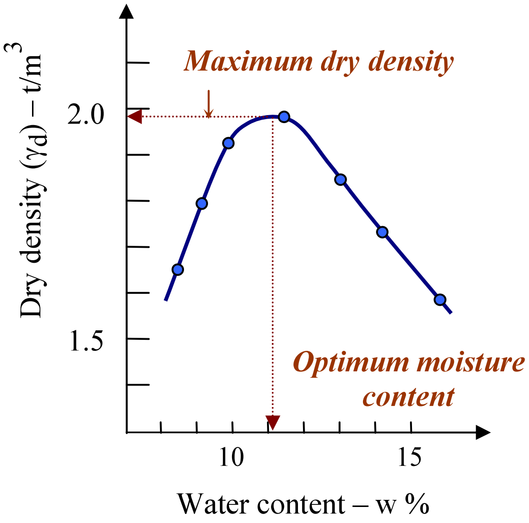


Fig. 10.1 Water content-dry density relationship

The compaction characteristics are determined in the laboratory by various compaction tests. These tests are based on any one of the following types of compaction:

(a) Dynamic or impact compaction
(b) Kneading compaction.
(c) Static compaction.
(d) Vibrating compaction.

The main aim of these tests is to arrive at standard which may serve as a guide and basis of comparison for field compaction. There are several types of tests are described in the following section.

## 10.2 Standard Proctor test

وضع بروكتور (الامريكى) أسس اختبارى الدمك القياسى والمعدل عام ١٩٣٣ ليضع شروطا قياسية لعمليات دمك التربة لتنفيذ الطرق والمطارات . والفرق بين الاختبارين أن الاول يستخدم طاقة دمك صغيرة نسبيا مما يجعل الكثافة الجافة القصوى التى نحصل عليها تناسب الأعمال التى يتوقع فيها أحمالا صغيرة , كأساس الطرق الثانوية مثلا . أما الاختبار الثانى فيستخدم فيه طاقة دمك كبيرة نسبيا فيعطى كثافة جافة قصوى تناسب الأعمال التى يتوقع فيها أحمالا عالية مثل أساس الطرق الرئيسية والمطارات .

The standard proctor test is a dynamic compaction test, found to be suitable for road construction. It was originally designed for the construction of earth fill dams. The test equipment is shown in Fig. 10.2. It consists of:

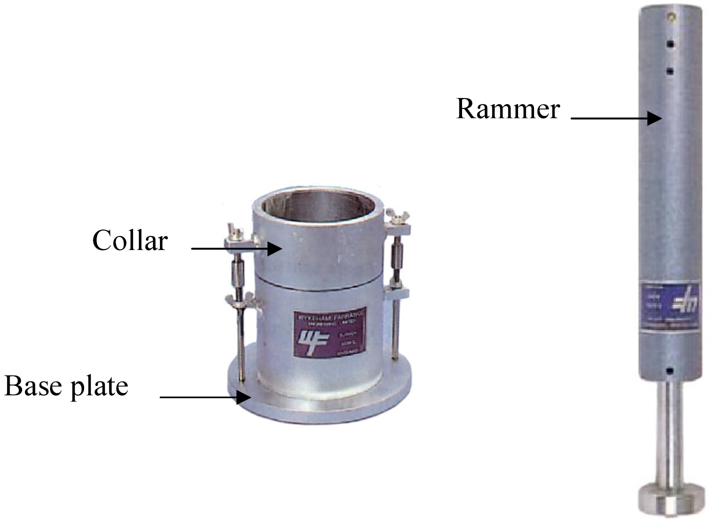


Fig. 10.2 Standard Proctor test equipment

(a) Cylindrical metal mould, 10 cm internal diameter and 12.7 cm high.
(b) Base plate.
(c) Collar 6 cm high.
(d) Rammer 2.5 kg in weight, falling through a height of 30.5 cm.

### 10.2.1 Procedure

The test consists of, compacting the soil into the mould at various water contents. The soil is compacted in three equal layers, each layer given 25 blows of the rammer. The bulk density of the soil filling the cylindrical mould is determined, and by measuring the water content, the dry density is obtained. The test is repeated on soil samples with increasing water contents and a compaction curve is plotted. The optimum moisture content and maximum dry density are determined.

## 10.3 Percentage air voids lines

يساعد رسم المنحنيات النظرية الخاصة بالعلاقة بين محتوى الرطوبة والكثافة الجافة للنسب المختلفة من الفراغات الهوائية فى إيضاح خواص التربة المدموكة ومدى إمكانية تحسينها .

The air voids content ($n_a$) of a soil is defined as follows:

$$n_a = \frac{V_a}{V} \qquad \text{… … … … … (10.1)}$$

where $V_a$ = Volume of air
$V$ = Total volume of soil

Now:

$$1 = \frac{V_a}{V} + \frac{V_w}{V} + \frac{V_s}{V}$$

$$= n_a + \frac{W_w \cdot W_s}{\gamma_w \cdot V \cdot W_s} + \frac{W_s}{G_s \cdot V}$$

$\therefore$

$$= n_a + \frac{W \cdot \gamma_d}{\gamma_w} + \frac{\gamma_d}{G_s}$$

$$\gamma_d = \frac{(1 - n_a) \cdot G_s}{1 + w \cdot G_s} \cdot \gamma_w \qquad \text{.. .. .. .. .. .. (10.2)}$$

The theoretical maximum compaction for any given water content corresponds to zero air voids ($n_a = 0$). The line showing the relation between the dry density and water content of a soil containing no air voids is called the zero air voids line, or saturated line, and is given by the equation :

$$\gamma_d = \frac{G_s}{1 + w \cdot G_s} \cdot \gamma_w \qquad \text{.. .. .. .. .. .. (10.3)}$$

Fig 10.3 shows zero, 5 , 10% air voids lines, these lines help as a check that compaction test has been properly carried out.

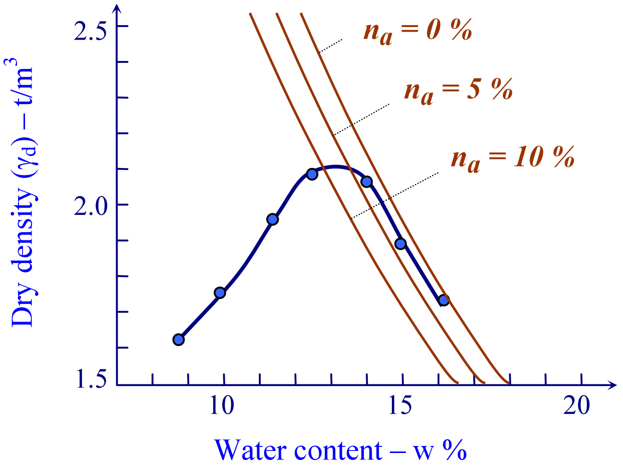


Fig. 10.3 Theoretical curves for different percentage of air voids

## 10.4 Modified Proctor test

Higher compaction is needed for heavier transport and aircrafts. The modified proctor test was developed to give a higher standard of compaction. The test is also known as AASHO test (American Association of State Highway Officials). In this test soil is compacted in the standard proctor mould, but in five layers, each layer 25 blows of a 4.5 kg rammer dropped – through a height of 45 cm. In the modified proctor test, the water content – dry density curve lies above the standard proctor curve, and its peak is relatively placed towards the left, Fig. 10.4. Thus, for the same soil, the effect of heavier compaction is to increase the maximum dry density and to decrease the optimum moisture content.

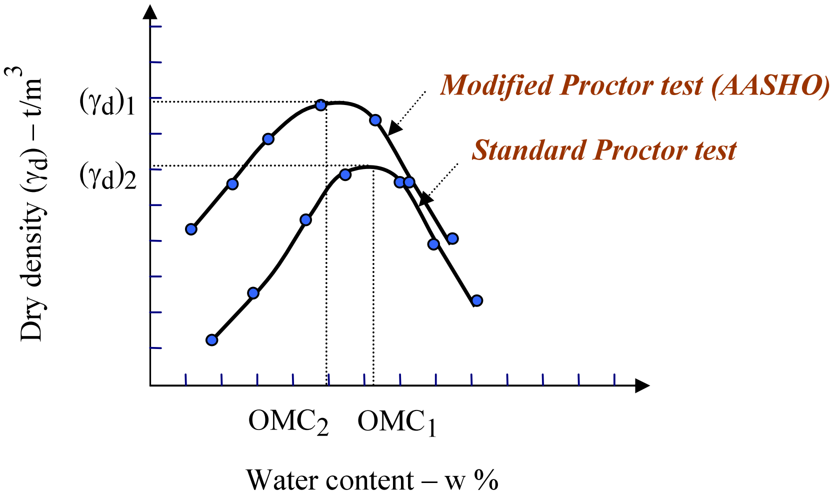


Fig. 10.4 Comparison between standard and modified Proctor test results

## 10.5 Effect of compaction on soil properties

The object of compaction is to improve the desirable properties of a soil, e.g. to increase soil strength and bearing capacity and to reduce compressibility, water absorption and permeability. The effect of compaction on soil properties depends very much on the structure which a soil attains during compaction.

عملية الدمك لهل تأثير على خواص التربة المختلفة . فبالنسبة الى
تركيب التربة الخشنة فالدمك يؤدى الى تقارب الحبيبات وزيادة عدد
النقط الاتصال بينها , إلا اذا احتوت التربة على نسبة عالية من
المواد الطميية والطينية بما يؤدى الى ان تكون الحبيبات الكبيرة

متفرقة "وعائمة" فى وسط من تجمعات الحبيبات الناعمة . ويمكن دمك التربة الخشنة بالهراس ذو العجل الكاوتش ويعطى الهراس الهزاز أفضل نتيجة . ويتم دمك كسر الحجر بالهراس ذو العجل الناعم (وابور الزلط) .

وبالنسبة الى التربة الناعمة فإن الدمك الاستاتيكى او بالاهتزاز لا يكون فعالا وإنما يستخدم الدمك هراس أرجل الغنم يحيث يتم عجن التربة فتندمك بفاعلية . ويلاحظ أن التركيب التربة الطينية المدموكة بمحتوى رطوبة أقل من المحتوى الأمثل يؤدى الى تكوين تركيب مفتوح ذو نفاذية ومقاومة قص عاليين وأيضا قابلية عالية للانتفاش. أما الدمك بمحتوى رطوبة أعلى من المحتوى الأمثل فيؤدى الى التركيب مبعثر ذو نفاذية ومقاومة قص منخفضين وأيضا قابلية منخفضة للأنتفاش. وقابلية التربة المدموكة للانضغاط تحت تاثير الأحمال الصغيرة تزيد اذا كانت التربة مدموكة بمحتوى رطوبة أعلى من المحتوى الأمثل , ولكن تحت تاثير الاحمال العالية تزيد قابلية التربة المدموكة للانضغاط اذا كانت مدموكة بمحتوى رطوبة أقل من المحتوى الامثل , ومع الأحمال العالية جدا تتساوى كثافة التربة سواء كانت مدموكة بمحتوى رطوبة أقل أو أكثر من المحتوى الأمثل .

### 10.5.1 Structure of compacted soil

The structure of a compacted soil depends on the type of soil, moulding water content and the type and amount of compaction

(a) Coarse grained soils with little or no fines:

Such soils maintain a single grained structure at any possible void or water content.

(b) Coarse grained soil with appreciable amount of fines:

The resulting structure depends upon the relative properties of the coarse particles and the fines. The two main types of particles arrangement are in the form of coarse grained skeleton structure when the plastic fines are only just sufficient to fill the voids of coarse particles which essentially maintain their single – grained structure, and cohesive matrix structure when the coarse particles do not touch one another but float in a compact matrix of clay.

(c) Fine grained soil consisting essentially of clay particles:

At low water content the adsorbed layer of water does not develop fully, which leads to low interparticle repulsion, and for most types of soils this leads to a flocculated structure with low degree of orientation of clay platelets. An increase in water content expands the adsorbed water layer, increase interparticle repulsion and tends to develop higher pore pressure when the compaction pressure is applied, consequently, the soil decreases in shear strength and compaction rammer is able to induce greater shear strain during compaction. The somewhat reduce tendency to flocculate, and more particularly the greater shear deformations occurring under the compacting rammer, can lead to an increased degree of dispersion or orientation of the clay particles in the compacted soil. A method of compaction which is capable of causing greater shear strains in the soil during compaction introduces greater degree of dispersion. Particle dispersion, thus, tends to increase in the following order of compaction methods:

Static ........................ Lowest dispersion
Vibrating ................ Medium dispersion
Kneading ................ Highest dispersion

### 10.5.2 Permeability of compacted soil

Permeability decreases with the increase of dry density of compacted soil because the voids are reduced. For the same dry density, fine grained soil samples, compacted dry of optimum, are more permeable than those compacted wet of optimum. This is because the samples compacted dry of optimum tend to have a more random orientation (flocculated structure); they have large pore size than the samples with more parallel orientation of particles (dispersed structure) obtained from wet side compaction. For any given void ratio, the large the size of individual pores the greater is the permeability.

### 10.5.3 Shrinkage and swelling of compacted soil

Soil samples compacted dry of optimum, having flocculated structures, shrink appreciably less than those of equal densities and compacted wet of optimum. Dry side compacted samples exert greater swelling pressure and swell to higher water contents than samples of the same density obtained from wet side compaction.

### 10.5.4 Compressibility of compacted soil

In low pressure range, a wet side compacted sample is more compressible than a dry side compacted sample, if both are saturated and have the same void ratios. This is because a wet side compacted sample has already oriented particles whereas on the dry side extra pressure is required to cause particles to be obtained from a flocculated structure. However, in high pressure range, a dry side sample is more compressible than wet side sample. A larger pressure may cause greater particle orientation and hence a greater volume change per unit increase of pressure in a sample compacted dry of optimum than in a wet side compacted sample which has already a more parallel orientation of particles. At some large pressure both dry side and wet side compacted samples have again nearly the same

### 10.5.5 Stress – strain characteristics of compacted soil

Dry side compacted samples having more flocculated structure produce much steeper stress – strain curve and develop their maximum strength at low strain. The more dispersed samples prepared on the wet side of optimum, having the same density, show much flatter stress – strain curves and continue to increase in strength even at high strain.

## 10.6 Factors affecting compaction

The factors which affect compacted density are as follows:

### 10.6.1 Water content

The effect of water content on density is given in Fig. 10.1. when only a relatively small amount of water is present in soil, it is firmly held by the electrical forces at the surface of soil particles, and adsorbed water is prevented from developing fully. This prevents the particles from moving over one another easily when compacted, and hence high percentage of air voids, and low density is achieved. The increase in water content results in an expansion of the adsorbed water layer and reduction in the net attractive forces between particles which permits the particles to slide more easily over one another into a more oriented and denser state of packing, the air voids approaches a constant value, as further increase in water content does not cause any appreciable decreases in them. The total voids due to water and air due to water and air in combination go on increasing with increase in water content, and hence the dry density of the soil decrease.

### 10.6.2 Amount of compaction

The effect of increasing the compaction energy results in an increase in the maximum dry density and decrease in the optimum water content, as shown in Fig. 10.5. It is shown that the increase in maximum dry density does not have a linear relationship with increase of compaction effort

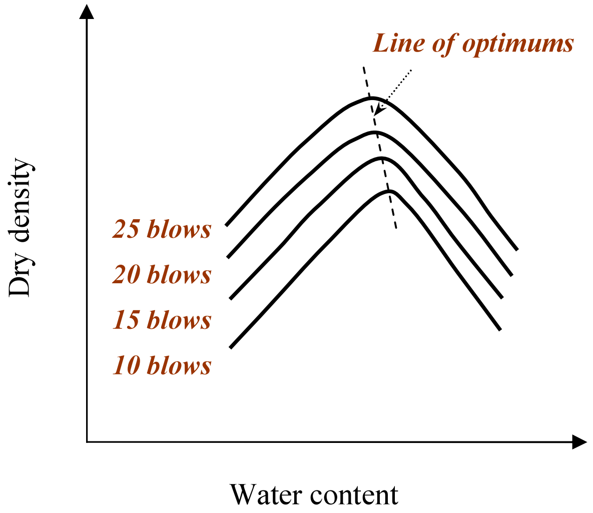


Fig. 10.5 Effect of compaction energy on the obtained compaction parameters

### 10.6.3 Type of soil

The maximum dry density achieved corresponding to a given compactive energy depends on the type of soil. Well graded coarse soils attain a much higher density and lower optimum moisture content than fine grained soils which require more water for lubrication because of the greater surface area of the particles.

### 10.6.4 Admixtures

In some cases admixtures are used in the soil to modify its compaction properties. For example, calcium chloride acts as a soil flocculent, and therefore facilitates compaction and usually causes a slight increase in the compacted density.

## 10.7 Field compaction methods

Compaction of soil in the field can be carried out by three main procedures:

### 10.7.1 Compaction by rolling

Rolling equipments are of three types:

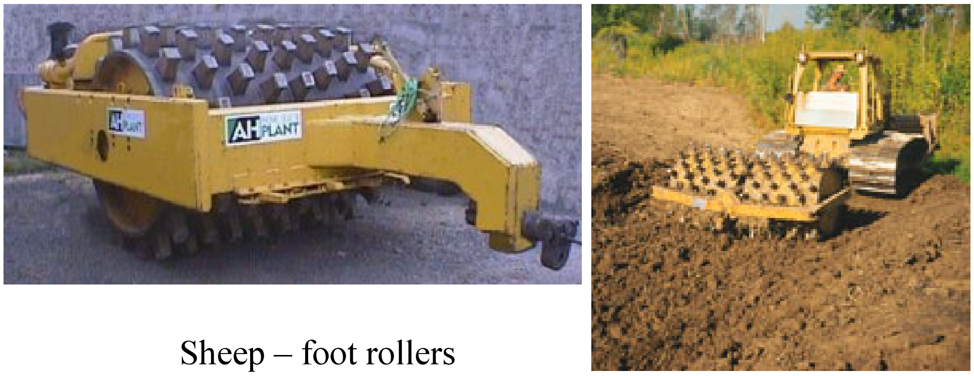
(a) Smooth – wheel rollers: These are the well know 3 – wheel type rollers, and these are available in different weights.

(b) Pneumatic – type rollers: They range from small wheel roller to very heavy 200 t rollers.

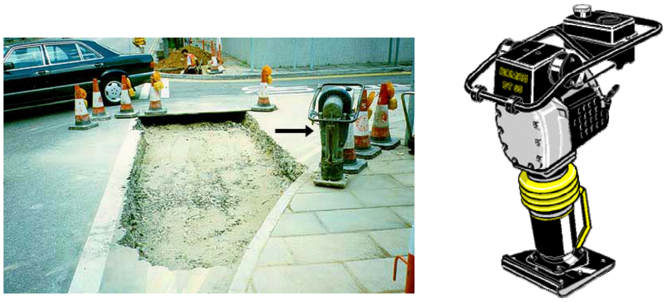
(c) Sheep – foot rollers: They consist of hollow cylindrical steel drum on which projected feet are mounted. The weight of the drum can be varied by filling it with water.

Smooth - wheel rollers

Pneumatic tyered



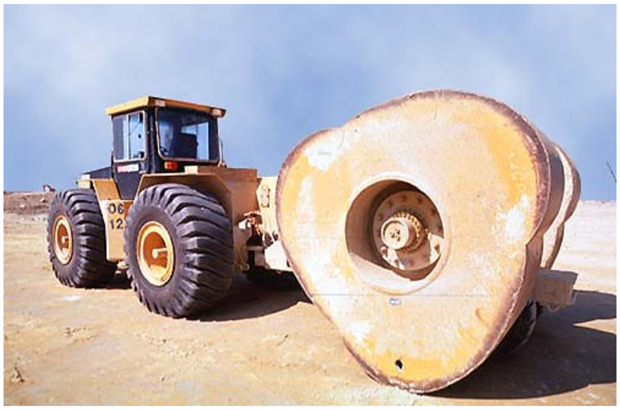
Sheep – foot rollers



Vibrating plates

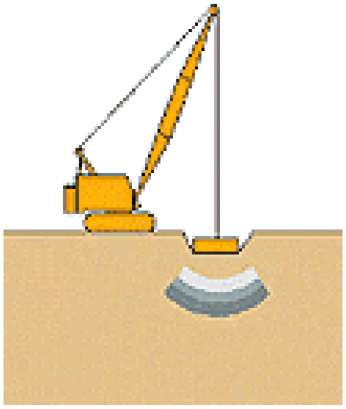
### 10.7.2 Compaction by rammers

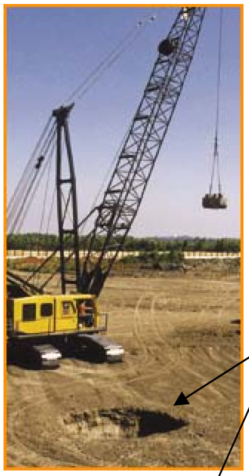
They are of pneumatic and internal combustion types, weighing from 30 to 150 kg. Internal combustion type jumping rammers known as frog rammers weigh up to 1 t. Impact roller provides deeper compaction, up to 2 to 3 m, therefore it is suitable for use in airfields.



Impact roller

## Dynamic compaction





"Holes"
created by the
impact, to be
backfilled

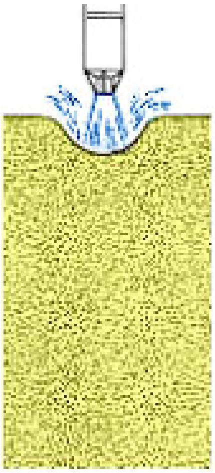
Dynamic compaction is the process of compacting the ground by a heavy weight of 5 to 30 t, lifted to a height of 10 to 30 m above ground. It is suitable for granular soils, land fills and land with sink holes. It is also recognised as a suitable solution for cavities in limestone.

### 10.7.3 Compaction by vibration

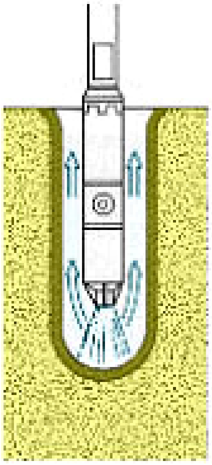
The vibrators comprise a vibrating unit, either an out of balance weight type or a pulsating hydraulic type.

**Vibroflotation:**

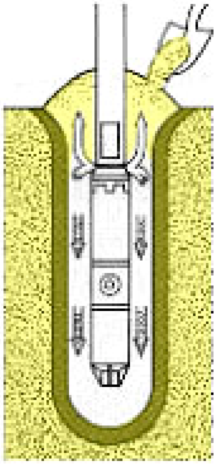
الفيبروفلوت معدة تستخدم فى دمك التربة الرملية المفككة للاعماق البعيدة ويستخدم الاهتزاز مع دفع المياه فى هذه العملية. ويتم تعويض الهبوط فى سطح الارض نتيجة تدامك التربة بإضافة رمال الى العامود الذى تم دمكه . ويستخدم الفيبروفلوت على مسافات فى حدود ٢ متر لتغطية الموقع المراد دمكه .



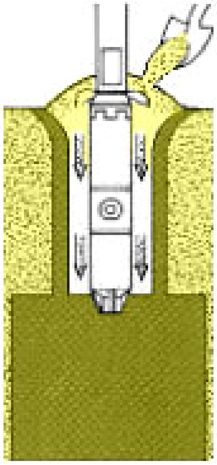
١- يثبت الفيبروفلوت على ونش عربة حاملة اعلى النقطة المراد دمك التربة بها ويفتح صنبور المياه السفلى.



٢- تدفع المياه من خلال الصنبور بمعدل عالى. ويشغل الفيبروفلوت بحركة اهتزازية فيخترق التربة بيسر (٢ الى ٤ متر / دقيقة )



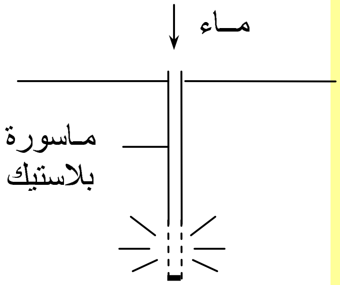
٣- يحول دفع المياه من اسفل الى الصنابير العلوية مع خفض الدفع بدرجة تسمح برجوع المياه للسطح ضمانا لتدامك التربة المضافة وسهولة وضعها.



٤- يكتمل الدمك برفع الفيبروفلوت اثناء اهتزازه بمعدل ٣,٠ متر / دقيقة حتى يصل للسطح واثناء ذللك يضاف الرمل ليصبح عمود التربة المدموك كثيفا بدرجة عالية جدا.

**The Vibroflot** (vibrating unit) length is 2 to 3 m, and 0.3 to 0.5 m diameter. Its mass is about 2 ton.

Vibroflotation is a process of compacting loose sands and gravels by vibration up to considerable depth. The device is known as the vibroflot, approximately 43 cm in out side diameter and about 2m long. The vibroflot is first lowered into the ground up to the desired depth by the jetting action of water. The vibroflot is then operated to compact the surrounding soil. As compaction takes place, additional material is shovelled into the crater formed around the vibroflot. The vibroflot is then raised about 30 cm at a time and the operation of compaction and back – filling is repeated. This way a cylindrical column of compacted material about 2.5 – 3 m in diameter is produced. Vibroflotation has been used up to average depth of about 10 m.



فى الشكل طريقة بسيطة لدمك التربة الرملية المفككة فى العمق وذلك بتغويص قاسون (ماسورة حديد قطر ١٥ سم) ثم وضع ماسورة بلاستيك مخرومة من طرفها السفلى داخل القاسون وخلع القاسون مع الأبقاء على الماسورة فى التربة ، ثم دفع مياه الى داخل التربة من خلال المواسير بما يؤدى الى تكثيف التربة . ويتكرر ذلك على مسافات فى حدود ٢ متر لتغطية الموقع المراد دمكه .

## 10.8 Suitability of various compaction equipments

The performance of a compaction equipment depends upon the soil type, its particle size distribution, and its water content. In general smooth – wheel rollers are most suited to crushed rock and mechanically stable gravels and sands. They can also be used satisfactorily in moderately cohesive soils. In cohesionless sands and gravels, vibrating type equipments and rubber – tyred rollers are effective. Sheep – foot rollers are recommended for compacting cohesive soils, but they are not considered effective on coarse – grained cohesiveless soils. They kneading action of the sheep – foot roller results in a better bound between compacted layers compared to other types of rollers. The acting of pneumatic tyre rollers is a combination of pressure and kneading. They are suitable both in cohesionless sands and gravels, and on cohesive soils. Rammers are used for compacting soils in confined places.

## 10.9 Control of field compaction

تجرى مراقبة مدى نجاح عملية الدمك بايجاد الكثافة الجافة للتربة المدموكة فى الموقع بطريقة الوعاء الرملى او قاطع القالب ومقارنتها بالكثافة الجافة القصوى المحددة بتجربة بروكتور القياسية او المعدلة. ويمكن استخدام طريقة غرز او دق جسم معدنى فى التربة ومعرفة المقاومة التى تعاير مع محتوى رطوبة التربة وبالتالى الكثافة الجافة المقابلة. ويمكن ايضا استخدام اجهزة الاشعاع الذرى او الموجات فوق الصوتية حيث تعاير قراءاتها مع المحتوى رطوبة التربة وكثافتها.

One of the essential requirements in proper construction of embankments is a very close control of the quality of earth – work which involves keeping of detailed records of the type of material used, thickness of layers, type of compaction equipments, number of passes and the results of compaction tests. Such a close control enables one to:

(a) Select proper fill material and improve compaction by increasing or decreasing their water contents.
(b) Select economic method of compaction which utilize the construction traffic and special compaction equipment.

The control of compaction can be carried out using the following method

### 10.9.1 Detailed laboratory tests

This involve extraction of samples of the compacted soil and determination of their water content, density and degree of saturation, also optimum moisture content and maximum dry density. The degree of compaction of the soil can be defined by the relation:

$$I_{comp.} = \frac{\gamma d(in-situ)}{\gamma d(max.)} \qquad \text{... ... ... ... ... (10.4)}$$

where: $I_{comp.}$ = index of compaction.

Acceptable minimum values of the index of compaction are determined depending on the specifications followed and the values of the maximum dry density.

### 10.9.2 Penetrometer tests

These tests involve inserting a certain rod into the ground and comparing the resistance to penetration in the field by that in the laboratory for various water contents in the proctor mould, thus knowing the field water content. Two types of penetrometers are described herein.

#### (a) Proctor needle

The proctor needle consists of a needle point attached to a graduated rod which is attached to a spring loaded plunger. Needle points of varying cross – sectional areas are available so that a wide range of penetration can be measured. The penetration force is read on a load gauge fixed over the handle, fig. 10.6. To use the needle in the field, a calibration curve is plotted in the laboratory between the penetration resistance and water content. The laboratory penetration resistance is measured by inserting the proctor needle in the compacted soil in the proctor water mould. The penetration resistances corresponding to various water contents are thus noted at the end of each proctor compaction and a calibration curve is plotted. This curve may be used to determine the placement water content. The penetration resistance of the compacted soil in the field is determined with the proctor needle and its water content is read off from the calibration curve.

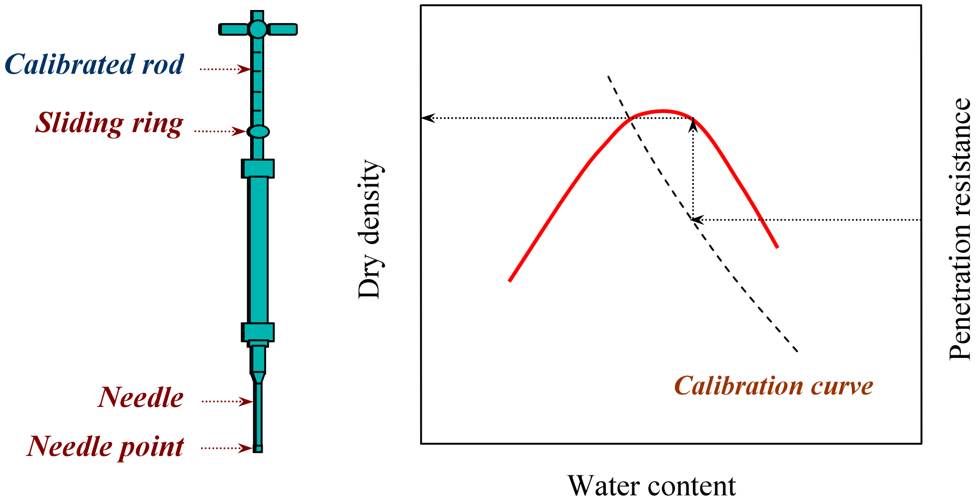


Fig. 10.6 The proctor needle and calibrated curve

### (b) Dynamic penetrometer

The number of blows per each 10 cm of penetrations of a 5 cm diameter conical penetrometer, driven by 20 kg mass falling through 25 cm, fig. 10.7 is counted. The conical penetrometer is held in a vertical position by a tubular guide fixed to q circular plate which should be loaded with the weight of the user. The standard number of blows should be established for typical soil used, on the basis of penetration tests carried out in places where the indices of compaction $I_{comp}$. have been accurately established with the detailed laboratory tests.

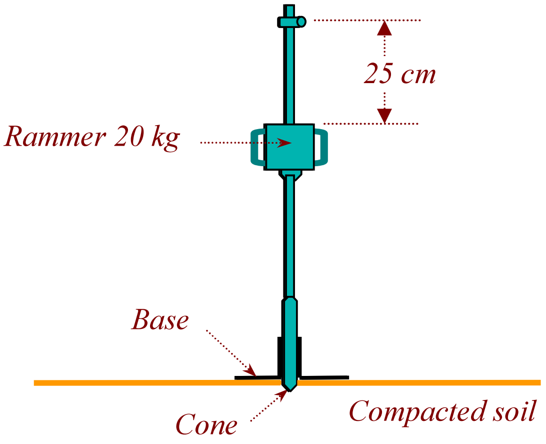


Fig. 10.7 Dynamic penetrometer

## (c) Nuclear control tests

Nuclear method of in – situ measurement of density and water content of soil have been recently developed, and widely used in the control of the compaction of all types of soils. One of the known types, called the back – scatter apparatus, has a source of Radiation and a detector contained in a unit which is placed on the surface of the material under test. The detector is separated from the source by a lead shield. Some of the gamma radiations and slow neutrons are scattered back and are detected by respective counters. As in the case of penetrometer tests, nuclear control tests should be spot checked at regular intervals with detailed laboratory tests.

## 10.10 Examples

(1) The following results were obtained from a standard compaction test. Plot the compaction curve. Find the maximum dry density and corresponding optimum moisture content. Plot also zero and 5 % air voids curves. Take $G_s = 2.68$.

| | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content - % | 10.1 | 11.8 | 14.2 | 16.3 | 17.6 | 18.9 |
| Bulk density – t/m$^3$ | 1.817 | 1.912 | 2.05 | 2.093 | 2.07 | 2.045 |

Solution:

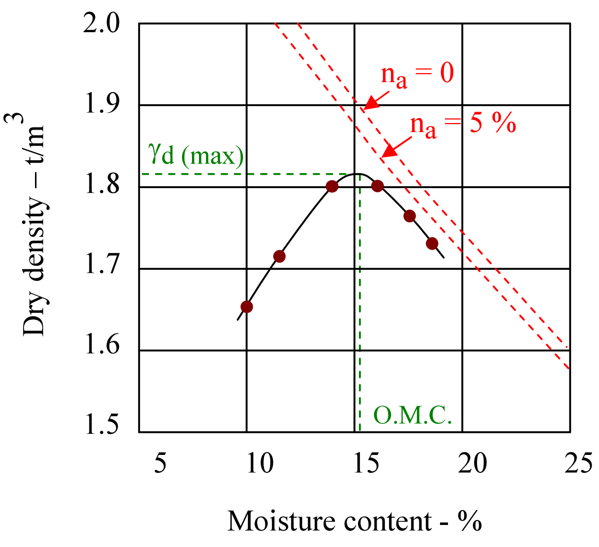
| | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content - % | 10.1 | 11.8 | 14.2 | 16.3 | 17.6 | 18.9 |
| Bulk density – t/m$^3$ | 1.817 | 1.912 | 2.05 | 2.093 | 2.07 | 2.045 |
| Dry density – t/m$^3$ | 1.650 | 1.710 | 1.795 | 1.800 | 1.760 | 1.720 |
| Dry density ($n_a$=0) – t/m$^3$ | 2.109 | 2.036 | 1.941 | 1.865 | 1.821 | 1.779 |
| Dry density ($n_a$=5%) – t/m$^3$ | 2.004 | 1.934 | 1.844 | 1.772 | 1.772 | 1.690 |

$$\gamma_d = \frac{G_s \, \gamma_w \, (1 - n_a)}{1 + w \, G_s}$$

From the compaction curve:

$\gamma_{d\,(max)} = 1.813$ t/m$^3$

O.M.C. = 15.4 %



(2) Results of a standard Proctor test gave maximum dry density of 1.75 t/m$^3$, and optimum moisture content of 12.5 %. The specific gravity of soil is 2.66. Find the degree of saturation and percentage of air voids at the optimum condition. Find the weight of dry soil and weight of water required to form a specimen 5 cm diameter and 10 cm high, after being compacted to the optimum condition.

Solution:

$$\gamma_d = \frac{G_S\,\gamma_W}{1+e}$$

$$\text{э}\ 1.75 = \frac{2.66 \times 1}{1+e}$$

$$\therefore\ e = 0.52$$

$$e \cdot S = G_S \cdot w$$

$$0.52 \times S = 2.66 \times 0.125$$

$$\therefore\ S = 63.94\,\%$$

$$\gamma_d = \frac{G_S\,\gamma_W\,(1 - n_a)}{1 + w.G_S}$$

$$1.75 = \frac{(1 - n_a) \times 2.66}{1 + 2.66 \times 0.125}$$

$$n_a = 12.34\,\%$$

For the required sample :

$$V = \frac{\pi\,(5)^2}{4} \times 10 = 196.35\ \text{cm}^3$$

$$Ws = 1.75 \times 196.35 = 343.61\ \text{gm}$$

$$W_W = 343.61 \times 0.125 = 42.95\ \text{gm}$$

(3) Results of a compaction test are given. If the minimum allowed degree of compaction is 95 %, find the range of water content which can be applied. Assume that in-situ compaction is carried out using the same energy as that used in the test.

| | | | | | | |
|---|---|---|---|---|---|---|
| Moisture content - % | 9.7 | 11.5 | 13.6 | 16.2 | 17.7 | 19.8 |
| Dry density – t/m$^3$ | 1.63 | 1.781 | 1.874 | 1.813 | 1.748 | 1.657 |

Solution:

From the compaction curve:

$$\gamma_{d(max.)} = 1.88\ t/m^3$$

O.M.C. = 14 %

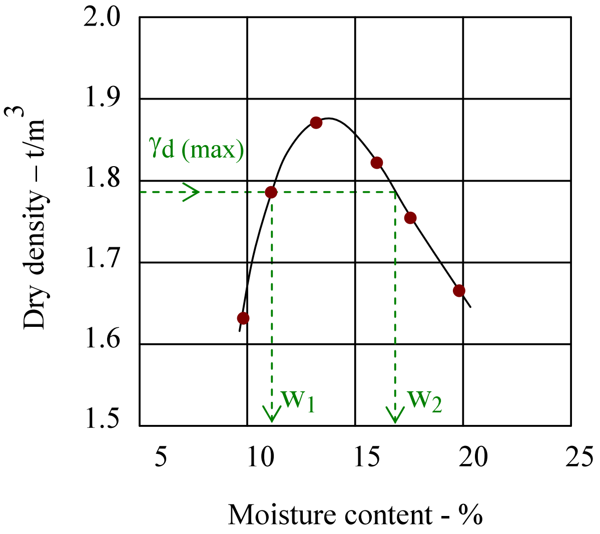
$$I_{comp.} = \frac{\gamma_{d(in-situ}}{\gamma_{d(max.)}}$$

$$\therefore 0.95 = \frac{\gamma_{d(in-situ}}{1.88}$$

$$\therefore \gamma_{d(in-situ)} = 1.786\ t/m^3$$

Range of water content

which can be applied: 11.55 to 16.7 %



## 10.11 Problems

(1) A standard Proctor test was carried out on a soil sample. The volume of the mould is 944 $cm^3$. The following results are obtained:

| | | | | | |
|---|---|---|---|---|---|
| Weight of wet sample - gm | 1566 | 1680 | 1727 | 1700 | 1632 |
| Water content - % | 7.3 | 10.4 | 12.8 | 16.6 | 18.9 |

Plot the water content-dry density relationship. Determine the maximum dry density and corresponding optimum moisture content. Plot the zero, 5% and 10% air voids curves. If a degree of compaction of 98 % is permissible, what is the placement water content range under the same compaction energy. Take $G_S = 2.67$.

(2) The following results were obtained from a Proctor test :

| | | | | | |
|---|---|---|---|---|---|
| Weight of mould + wet sample – gm | 3491 | 3621 | 3698 | 3665 | 3627 |
| Water content - % | 9.7 | 12.0 | 15.4 | 16.7 | 18.5 |

Knowing that the weight of the mould is 1800 gm and its volume is 940 $cm^3$, find the maximum dry density and corresponding optimum moisture content.

(3) A standard Proctor test gave maximum dry density and optimum moisture content values of 1.71 $gm/cm^3$ and 16 %, respectively. When the compaction energy was increased, the maximum dry density increased to 1.78 $gm/cm^3$. Estimate the optimum moisture content for the Increased energy. Assume that the line of optimums is approximately parallel to the zero air voids line. Take $G_s = 2.65$.

(4) The maximum dry density obtained from standard Proctor test is 1.73 $t/m^3$, and the optimum moisture content is 16.1 %. The specific gravity of soil is 2.68. Find the degree of saturation and percentage of air voids at the optimum condition. What is the increase of water content for full saturation without change of volume.

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